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PREVENTION OF THE EROSION OF FARM LANDS BY TERRACING.

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CONTENTS.

INTRODUCTION.

The existence of vast areas of so-called worn-out hill lands throughout the United States may be attributed chiefly to soil erosion, due to the natural agencies of wind, frost, and rain. In most localities wind and frost, owing to their comparatively slow processes, play but a minor part in the depletion of the soil and the ultimate destruction of good farm lands. It is the failure of the soil to absorb the rain water which falls upon it that presents by far the most serious aspect of the problem. It is estimated[1] that the Potomac River each year carries off in solution about 400 pounds of solid

[1] Bulletin 17, North Carolina Geological and Economic Survey, p. 21.

NOTE.—This bulletin treats of terracing as a means of preventing erosion of hillside land. It describes the different types of terraces and points out the applicability of each to the various kinds of soil and topography. It discusses the principles of terrace design. While the investigations upon which the recommendations are based were made in the Southern States, the information is applicable generally to any State in the humid section.

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matter per acre of land drained, containing plant food sufficient to produce a crop. Unless this loss be replaced by natural agencies or by the application of fertilizer, it is obvious that the land soon will deteriorate greatly in productiveness and eventually be abandoned.

In addition to the loss of the soluble elements of the soil, a noticeable impairment occurs in the physical condition of the soil. When the moving water washes the soil particles from the surface of the hillside and deposits them on the land below, the heavier particles, or the sandy constituents of the soil, are deposited first, and the finer, or clay, parts last. Since neither pure sand nor pure clay possesses the productive characteristics observed in a soil composed of the proper intermixture of sand and clay particles, it is apparent that the effect of this sorting process is to diminish greatly the fertility or productive power of the soil. Hence, not only the eroded land suffers but also the land at a lower level upon which the eroded material is deposited. Portions of the flood plains of small streams often are covered with a layer of sand, the fertility of the land so covered being practically destroyed, since it is a most difficult task again to build up a productive soil over such areas. Drainage channels, also, constructed at considerable cost, often become filled with soil washed from the hill lands. (See Pl. I, fig. 1.) As a result the adjoining bottom land reverts to swamp and becomes unprofitable for cultivation.

FORMS OF EROSION.[1]

Erosion due to moving water occurs in two forms—sheet washing and gullying. Small areas are practically ruined by gullying (Pl. I, fig. 2), while sheet washing (Pl. II, fig. 1) diminishes the productive power of large areas.

Gullying generally is the most dreaded of the two types on account of its more apparent destructive effects. Where the ravages of erosion proceed unchecked, deep gullies invariably develop in the field. Their appearance causes not only absolute loss of land and inconvenience in cultivating, but a marked lowering in the water table, with a possible accompanying inability of the soil to retain the proper moisture content for the production of crops and to withstand periods of drought.

The injury due to sheet washing, which occurs throughout the United States, generally is underestimated and is regarded by many farmers as of no particular consequence. It is this type of erosion that slowly carries away the very fertility of the soil without apprising the farmer—except through slightly diminished crop yields each year—that the application of remedial measures is imperative in order to save his farm. To the very slowness of its action can be

[1] For a more extended discussion of the translocation of soils, see U. S. Dept. Agr. Bul. 180, by R. O. E. Davis.

ascribed the difficulty often encountered in convincing the landowner that destructive erosion is taking place on his farm.

In some sections of the United States, particularly in the South, erosion is assisted materially by the alternate freezing and thawing of saturated soil. (Pl. II, fig. 2.) The freezing process upheaves a thin layer of the soil near the surface. As this layer of loosened soil thaws, it settles, with a tendency to move slightly down the slope. It is very common for heavy rains to occur directly after the thawing period and wash away the loosened soil from the surface of the field. Probably no other combination of natural conditions could operate more effectually to rob a field of its most fertile soil in the same period of time.

METHODS OF PREVENTING EROSION.

Erosion is due chiefly to the free movement of water over the surface of the land, which carries off particles of soil. If all rain water were absorbed by the ground upon which it falls, soil erosion would be reduced to a minimum. It is obvious, therefore, that in order to prevent or reduce erosive action the soil must receive treatment that is conducive to the admission and the storage of large quantities of rain water; and methods must be employed to reduce the velocity, and thereby the transporting power, of the run-off water.

Since the storage capacity of a soil depends upon its porosity, any treatment which results in an increased porosity of the soil will reduce erosion materially. This porous condition usually is obtained directly by deep plowing and by a thorough incorporation of organic matter in the soil. Methods of subsurface drainage which lower the ground water level improve the porous structure of the soil and increase its ability to absorb surface water. The treatment of cover, such as seeding land to pasture, growing timber, and planting cover crops in the winter, tends to check and diminish erosion greatly. Other methods which retard the flow of the water and conduct the excessive run-off from the field with a reduced amount of erosion, are contour plowing, hillside ditching, and terracing.

It is the purpose of this paper to deal primarily with the prevention of erosion by means of terracing; but since all of the methods of prevention enumerated above tend to mitigate the destructive effects of erosion, some of them should be used invariably in connection with terrace systems. The manner in which each contributes to the prevention of erosive action will be described briefly.

DEEP TILLAGE AND APPLICATION OF HUMUS.

By deep plowing the absorptive power and reservoir capacity of a soil is increased greatly. It is said[1] that 10 inches of loose, plowed

[1] Soil Report N. 3, Illinois Agricultural Experiment Station, p. 16.

soil will absorb 2 inches of rainfall. The incorporation of organic matter or humus in a soil adds materially to its moisture-holding capacity. This is best accomplished by plowing under deeply, manure, stubble, stalks, and various cover crops. This organic matter, in a decomposed state, is capable of absorbing considerable water and forms a richer and deeper top soil.

USE OF COVER CROPS.

Vegetation or cover crops will protect the soil in four ways: (1) by holding rain water on the surface for a time, thus giving the soil a better opportunity to absorb the water; (2) by keeping the soil open through the growth of the roots, which form passages for the water to reach the subsoil; (3) by holding the soil particles together through the binding power of the roots; and (4) by reducing the movement of soil particles through diminishing the velocity of surface water. Cover crops usually are grown during the winter or when the land is not being used for other crops. Their importance as a means of protecting land from erosion at such times can not be emphasized too strongly. Vetch, clover, cowpeas, wheat, and rye are used commonly for this purpose. It can be said generally that good farming and the use of cover crops go hand in hand.

PRACTICE OF LEVEL CULTURE.

Contour plowing and the following in general of practically level lines in farm operations tend to check the surface flow down a slope and to retain the water where it falls. In cultivating crops each row is banked up and a shallow depression which holds the surface water is left between the rows. Thus the absorption by the soil of this impounded water is facilitated and the rapid run-off down the slope, with its destructive eroding power, often is entirely eliminated in case of ordinary rains. Contouring contributes also in a considerable degree to the conservation of moisture on hill lands. The very apparent benefits of this practice merit its universal use on lands subject to erosion.

PASTURING AND FORESTING.

Often it seems impossible to prevent erosion on lands with excessive slopes. No attempt should be made to cultivate such areas but they should be seeded to meadow or pasture and usually retained as such. In well-sodded land the soil is not exposed directly to the erosive action of the water, so that erosion is much less destructive than in cultivated fields.

In many sections of the country timberland on excessively steep slopes has been cleared for cultivation, and in many instances after

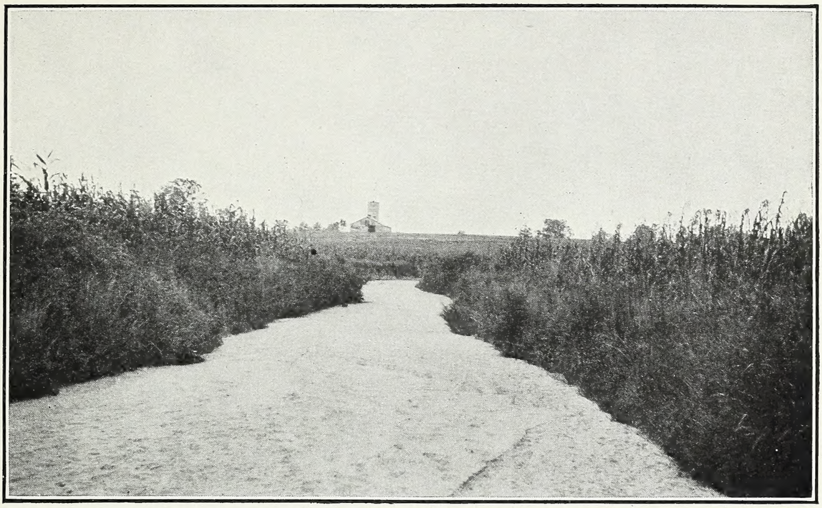

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FIG. 1.—DITCH PARTIALLY FILLED WITH SANDY SOIL ERODED FROM UPLAND.

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FIG. 2.—EROSION IN THE FORM OF GULLYING.

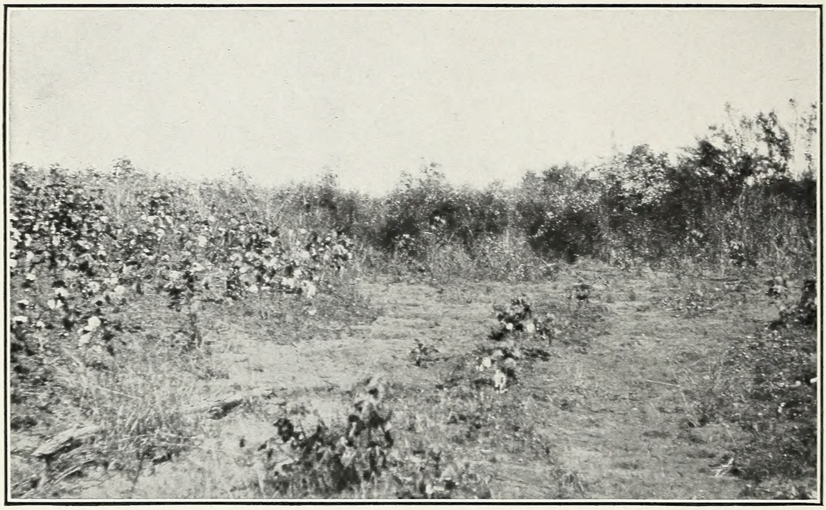

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FIG. 1.—EROSION IN THE FORM OF SHEET WASHING.

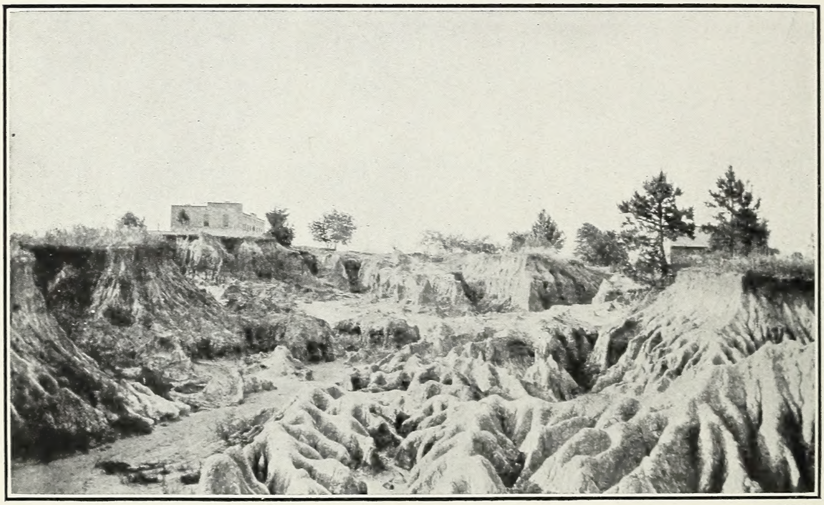

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FIG. 2.—EROSION ASSISTED BY ALTERNATE FREEZING AND THAWING OF THE SOIL.

clearing it was found impossible to control or check the erosion. Such lands should be reverted to timber; otherwise the ravages of erosion will reduce it soon to a state of barrenness. It is known that erosion is least active in forested areas, because of the penetration and binding power of the roots and the accumulation of a thick layer of leaves and organic matter on the soil surface. The soil possesses great coherence and power of resistance to the erosive action of the water and the layer of humus protects the surface and also absorbs considerable water.

UNDERDRAINING.

It can be seen readily that by the underdrainage of land to carry off the excess water from the soil space is created for the reception of more water from the surface. The water falling upon the surface sinks into the soil, percolates through it, and is conducted away by the underdrains to an open drainage channel without running over the surface and causing destructive erosion. Entrapped air, which often prevents the entrance and free movement of water in the soil, finds a means of escape through subdrainage channels. The physical condition of the soil is altered by underdrainage through the aeration and flocculation of the soil particles. A perceptible expansion and a slight upheaval of the soil take place, resulting in an increase in the size of the individual pore spaces. Hence, the rainfall percolates more easily and quickly into the soil and a diminution in the run-off follows. This system of draining is accomplished best by the use of tile drains.

USE OF HILLSIDE DITCHES.

Hillside ditches, as the name implies, are ditches constructed on hillsides to intercept run-off water and carry it at a low velocity to the nearest open drainage channel. Wherever this method of preventing erosion is employed there is likely to be a constant, perceptible draining off of the finer particles of soil, and a continual enlargement of the ditch takes place, the extent depending upon the amount of fall given to the ditch. (See Pl. III, fig. 1.) It is inadvisable, therefore, to resort to this method except when it is necessary to intercept surface water from adjoining higher land on which methods of preventing erosion are not employed. Sometimes hillside ditches are constructed to serve as outlets for systems of graded terraces where natural drainage outlets are not available.

TERRACING.

The greatest benefits from the foregoing methods of prevention come when they are applied in connection with a system of terraces.

Terracing affords the best means of conserving the hillside soils against the washing due to heavy rains.

A field trip was made by the writer through the States of North Carolina, South Carolina, Georgia, Alabama, and Mississippi for the purpose of studying the nature, causes, and effects of erosion, and more particularly the method of preventing erosion by means of terraces. Surveys of terraced fields which afford typical examples of every form of terrace in use were made with a view to deducing from a close study of the field data comprehensive and definite instructions for the design and construction of adequate and efficient systems of terraces. It was found that a great diversity of opinion exists among the landowners as to the best form of terrace and in the rules employed in planning a system of terraces. However, this difference of opinion, in most cases, could be attributed directly to varying conditions of soil and topography or to differences in farming methods.

The subject of the proper methods of terracing was discussed at length with experienced farmers—men who are pioneers in the practice of terracing and who are interested vitally in the preservation of their lands for themselves and their posterity. The deductions and conclusions reached are the result of an endeavor to treat from an engineering standpoint the information obtained from actual observation of field conditions in connection with the data derived from field surveys and the advice and opinions of the best informed and most experienced farmers.

DEFINITION AND CLASSIFICATION OF TERRACES.

As applied to the protection of farm lands, a terrace is any arrangement or disposition of the soil the object of which is to retard the rapid movement of surface water and thereby arrest the process of erosion. According to the earliest practice, terracing consists of building land up in a series of level areas resembling stair steps, the interval between the risers being horizontal and the riser itself being vertical or nearly so. This type of terrace has long been used extensively in Europe and China and is used to a great extent on the steeper lands in the United States. It is known generally as the level bench terrace, but to avoid confusion in the use of the term "level" it will be referred to in this paper as the horizontal bench terrace. Strictly speaking, this is the only true terrace, but the word "terrace" in this country is applied also to ridges of soil thrown up and located in such manner as to prevent the rapid flow of water down a slope. This type of terrace will be referred to in this paper as the ridge terrace to distinguish it from terraces of the bench type. The following classification (fig. 1) of terraces shows the various forms of bench and ridge types.

The bench type of terrace is subdivided into two classes, the horizontal and the sloping, the essential difference between the two being shown clearly by figure 1. Practically all terraces of the bench type are level, which means that they have no fall along the direction of their length to drain off surface water to the edges of the field or to an outlet channel.

The ridge type of terrace is subdivided into two general classes, the graded and the level, depending upon whether it has fall in the direction of the terrace to carry off the surface water. Graded and level-ridge terraces are subdivided further into two classes with respect to breadth of base, namely, the broad-base and the narrow-base forms. The broad-base graded terrace is subdivided again with

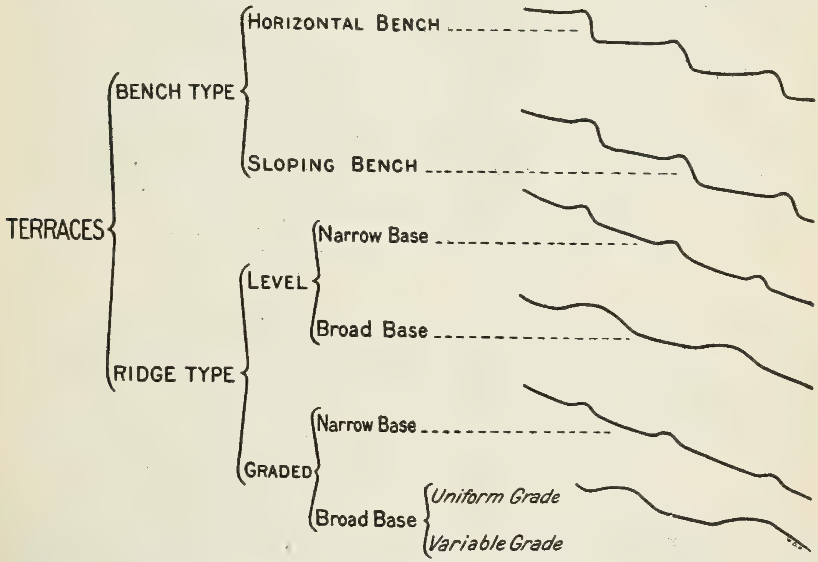

FIG. 1.—Classification of terraces.

respect to grade, the uniform-graded and the variable-graded terraces. Figure 2 shows actual profiles taken on terraced fields and illustrates the various types.

THE BENCH TERRACE.

Bench terraces, as stated, are of two classes—the horizontal and the sloping—depending upon whether the bench is horizontal or sloping. There are not many good examples of the true horizontal-bench terrace in this country, while the sloping-bench terrace is quite common. (See fig. 2–A, and Pl. III, fig. 2.) This is due to the fact that the horizontal bench is developed from the sloping bench by the gradual movement of the soil down the slope, owing to erosion, and to the use of the hillside plow, which always throws the soil down the slope. The time required for the leveling down of a sloping bench

depends upon the amount of soil moved down the slope each year and upon the vertical distance between the terraces. It is necessary to maintain a shoulder of earth at the lower side of the bench for sloping-bench terraces, and it is advisable that this be done for horizontal-bench terraces, for the purpose of retaining that portion of the rain water which does not sink into the soil. This shoulder and the lower side of the embankment should be seeded to grass. (See Pl. IV, fig. 1.) The sod permits the use of a steep slope on the lower

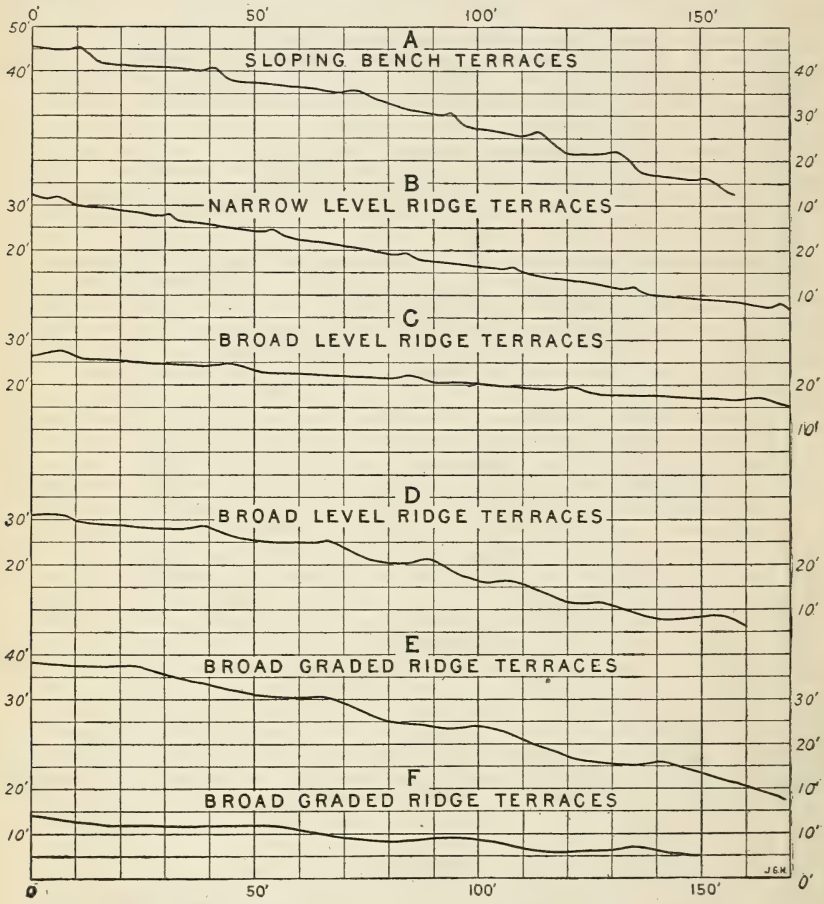

FIG. 2.—Actual profiles of terraced fields, taken across terraces.

side of the embankment and protects both the shoulder and the embankment from erosion due to surface water overtopping the shoulder. The leveling-down process mentioned above sometimes is continued until the slope of the bench is reversed. Thus, the water falling on the bench will flow to the foot of the embankment above. In this case no shoulder will be required to prevent the water from washing over and eroding the embankment.

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FIG. 1.—HILLSIDE DITCH WHICH IS WASHING BADLY.

D663

FIG. 2.—FIELD OF SLOPING BENCH TERRACES.

D176

FIG. 1.—VIEW OF LOWER SIDE OF SLOPING-BENCH TERRACE EMBANKMENT.

D188

FIG. 2.—FIELD OF NARROW-BASE LEVEL-RIDGE TERRACES.

Figure 3 shows a cross section of two adjacent sloping-bench terraces, with the various dimensions designated by letters for reference.

Surveys were made of a number of fields in the Piedmont sections of Georgia and South Carolina which have sloping-bench terraces. The average dimensions of the terraces in each field were determined. The minimum and maximum of these averages are shown in the following table:

Actual dimensions[1] *of sloping-bench terraces.*

Dimension.	Field averages.	
	Minimum.	Maximum.
Height of shoulder, *h*........feet..	0.4	0.8
Width of upper side of shoulder, *b*........do....	1.8	2.3
Vertical distance between terraces, *v*........do....	3.4	10.4
Ratio of *c* to *d*........per cent..	58	121
Slope of land........do....	5.5	28

[1] See fig. 3.

A comparative study was made of the conditions existing in the fields and the data obtained from the surveys with a view to ascertaining proper values to use in constructing a terrace of this style.

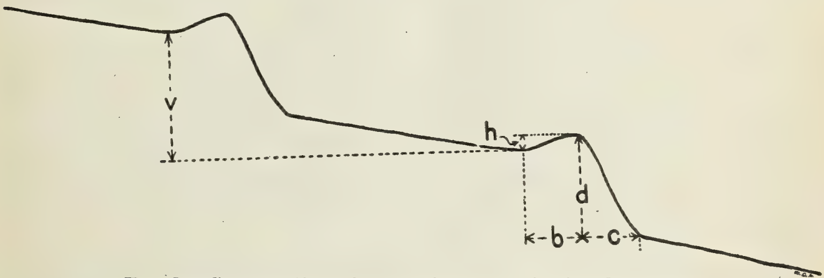


FIG. 3.—Cross section of two adjacent sloping-bench terraces.

The best terraces were found where the greatest height and width of shoulder were used with the smallest vertical distance between the terraces. It is believed that the height of shoulder (h) should be not less than 0.5 foot for horizontal-bench terraces or less than 1 foot for newly constructed sloping-bench terraces, and that the width (b) should be not less than 2 feet for the former or less than 3 feet for the latter. The vertical spacing between the terraces should be governed by the type of soil, the slope of the land, and the ease of starting and maintaining a heavy sod on a steep and high embankment. The best practice indicates that this spacing never should be less than 3 feet or more than 6 feet. The smaller spacing should be used on gently sloping land while the greater spacing applies to steep land. The question of proper spacing depends to a great extent upon the care and maintenance of the terraces. Unless considerable attention is to be given to the maintenance of the terrace banks the smaller

spacing should be used. For the 3-foot spacing a greater number of terraces are required and narrower benches result, but the terraces are easier to build and maintain than for a greater spacing. However, many farmers favor the wider benches because of the fewer terraces required and the fact that it is more convenient to cultivate the field in a few broad strips than in a greater number of narrow ones. In other words, they are willing to incur a greater loss by erosion for the sake of greater convenience in cultivation.

The slope of the terrace bank, or the ratio of *c* to *d*, was found to range from 58 to 121 per cent. It is believed that this bank could be maintained easily at a slope of ½ to 1, or 50 per cent. This would reduce the area of waste land in a terraced field.

The curves in figure 4 show the widths of bench for different vertical spacings on land of various slopes. Each curve is drawn for a certain vertical spacing between terraces. The widths of bench are computed for horizontal-bench terraces having a slope of ½ to 1 for the terrace banks. When constructed and maintained properly, bench terraces give excellent protection against erosion. However, many landowners object to this terrace on account of the difficulty of moving farm machinery from one bench to another, the necessity of cultivating each bench separately, the loss of the land occupied by the uncultivated embankments, and the growth of weeds and grass on the embankment, which robs the adjacent cultivated soil of its plant food and tends to seed the entire field to weeds and objectionable grasses. These reasons are sufficient to militate against the use of this terrace except on steep slopes where no form of cultivable terrace can be employed.

The best practice indicates that the bench terrace should not be used on slopes exceeding 20 per cent. However, they are actually in use on slopes up to 30 per cent, with a vertical interval of 8 to 10 feet; but in such instances the labor of cultivating the narrow benches and of maintaining the high embankments is considerable, and it is believed that such slopes could be devoted more profitably to pasture or timber.

THE LEVEL-RIDGE TERRACE.

The narrow-base form.—The narrow-base level-ridge terrace (see fig. 2–B, and Pl. IV, fig. 2) is used to a great extent throughout the Piedmont region of the South. It is essentially the first stage in the construction of a bench terrace, but methods of plowing are employed to prevent it from developing into a terrace of the bench type. It is built usually 3 to 5 feet wide at the base and from one-half to 1 foot high. Where these terraces are sodded heavily they render satisfactory service on pervious soils and slopes not greater than 5 to 8 per cent. They should be spaced from 2 to 3 feet apart in vertical distance. A close spacing reduces the volume of water

which collects above the terraces, and the sodded surface prevents erosion of the terrace due to impounded water overtopping it.

This type of terrace is cheap to construct, easy to maintain, and affords a very convenient guide row in plowing and planting. The

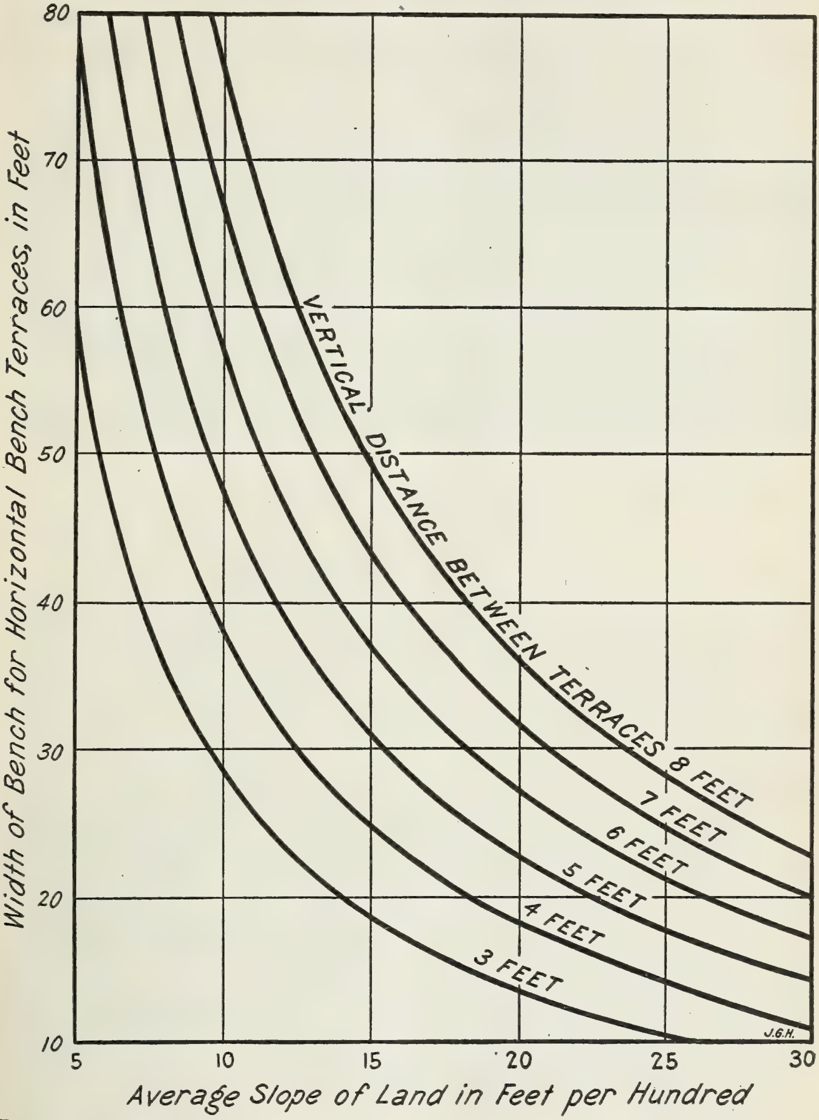


Fig. 4.—Horizontal-bench terraces. Curves showing width of bench for different land slopes and vertical distances between terraces.

principal objections to its use are (1) the land occupied by the sodded terrace reduces the total amount of tillable land in the field; (2) the growth on the terrace saps the strength from the adjoining soil, resulting in a dwarfed plant growth on either side of the terrace;

and (3) the weeds which often are allowed to grow on the terrace tend to seed the entire field, and harbor objectionable insects in the winter. Owing to these objections, this type of terrace is losing favor rapidly among the most advanced farmers.

Some attempts have been made to cultivate this terrace and thus do away with the objectionable features, but such attempts have been attended with very little success, except where the soil is very sandy and capable of absorbing most of the rain water as fast as it falls. Where this water is not absorbed readily by the soil, it concentrates above the terrace, generally breaks it and rushes down the slope, usually washing a deep gully and carrying away large quantities of fertile soil.

The broad-base form.—The many disastrous attempts to cultivate the narrow-base level-ridge terrace on all types of soil have led to the development of a terrace with a broader base, known as the broad-base level-ridge terrace. (Fig. 2–C and D, and Pl. V, fig. 1.) The broad-base embankment of earth provides the strength necessary to withstand the weight of the impounded water above, and the ter-

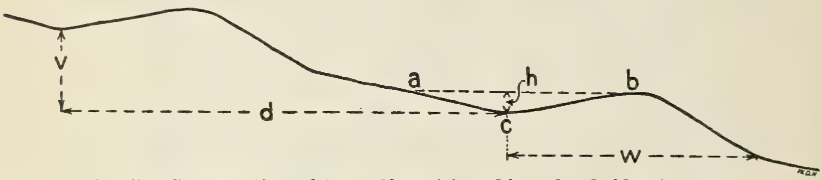


Fig. 5.—Cross section of two adjacent broad-base level-ridge terraces.

race is built sufficiently high to hold all run-off water from the drainage area above the terrace.

Surveys and examinations were made of several fields provided with these broad-base terraces in Alabama, Georgia, North Carolina, and South Carolina, and much information was obtained from farmers with many years of experience in the successful use of this type of terrace. A thorough study has been made of the data collected in connection with existing field conditions for the purpose of standardizing the dimensions employed in the construction of this terrace for different slopes of land and types of soil.

Figure 5 represents a cross section of two adjoining broad-base level-ridge terraces, with the various dimensions designated by letter. The vertical height of the terrace above the point c is represented by h; w is the width of the base of the terrace, d the horizontal distance, and v the vertical distance between terraces. These dimensions were obtained from surveys of eight fields representing the best practice in the use of this form of terrace. The average dimensions of the terraces in each field were determined. The minimum and maximum of these field averages are shown in the following table, together

FIG. 1.—VIEW OF LOWER SIDE OF A BROAD-BASE LEVEL-RIDGE TERRACE; COTTON ROW ON TOP OF TERRACE.

FIG. 2.—TERRACE OUTLET IN DEPRESSION OF FIELD, SEEDED TO GRASS TO PREVENT EROSION.

with the absolute minimum and maximum values found in the surveys:

Actual dimensions[1] *of broad-base level-ridge terraces.*

Dimension.	Absolute minimum.	Absolute maximum.	Field averages.	
			Minimum.	Maximum.
Base width of terrace, w .... feet..	5	18	6.8	11.6
Height of terrace, h .... do....	.5	1.6	.8	1.4
Vertical distance between terraces, v .... do....	1.9	6.1	2.7	4.8
Slope of land surafce .... per cent..	1.4	21.5	2.7	11.8

[1] See fig. 5.

From a study of the above data and observation of field conditions, it is believed that a broad-base level-ridge terrace should be not less than 1¼ feet high and at least 10 feet broad at the base. Methods of plowing and cultivation should be adopted which will tend to increase the base width from year to year and thus virtually transform the whole field into a series of terraces. (See fig. 2–D.)

Since the stability of a broad-base level-ridge terrace with closed ends depends upon its ability to retain the surface run-off water due to rainfall over the area between it and the next terrace above, it is apparent that the reservoir capacity above the terrace must be sufficient to store this water. Upon this principle are based the following remarks on the design of a system of broad-base level-ridge terraces.

Referring to figure 5, it is seen that the cross-sectional area of the water that can be stored above a terrace is represented by the area *a c b a*. A plan view of the line to which water is backed up before overtopping the terrace is shown in figure 6. A good idea of the size of the reservoir area can be obtained from this plan. Assuming that no water escapes around the ends of the terrace and that no water is lost through percolation into the soil, it follows that for the retention of all of the surface water the area *a c b a* (fig. 5) must be made equal to the product of the depth of the rainfall and the horizontal distance d. If percolation does take place, then the amount of water lost should be deducted from the total amount of rainfall. By equating the amount of surface run-off to the amount of storage above the terrace per unit of length, the following expression is obtained:

$$\frac{dr}{12}=\frac{dh^2}{2v}+\frac{wh}{4}, \text{ or } v=\frac{600h^2+3hws}{100r}$$

where r=surface run-off depth, in inches; h=height of terrace, in feet; w=base width of terrace, in feet; v=vertical distance between terraces, in feet; d=horizontal distance between terraces, in feet; s=slope of land, in feet per hundred, $=\frac{100v}{d}$.

It is assumed that the cross section of the stored water is triangular in shape.

Using the values, h=1.25 feet. and w=10 feet, then

$$v=\frac{9.375+0.375s}{r}$$

Hence, if the values of r and s are known, v, the vertical distance between the terraces, can be computed from the above equation. The value that should be assigned to r depends upon the absorptive capacity of the soil and upon the amount of rainfall for the heaviest single storm. From a general study of the rainfall records for the United States it is found that rainfalls exceeding 8 inches per 48 hours do not occur frequently in a given locality, and it is believed

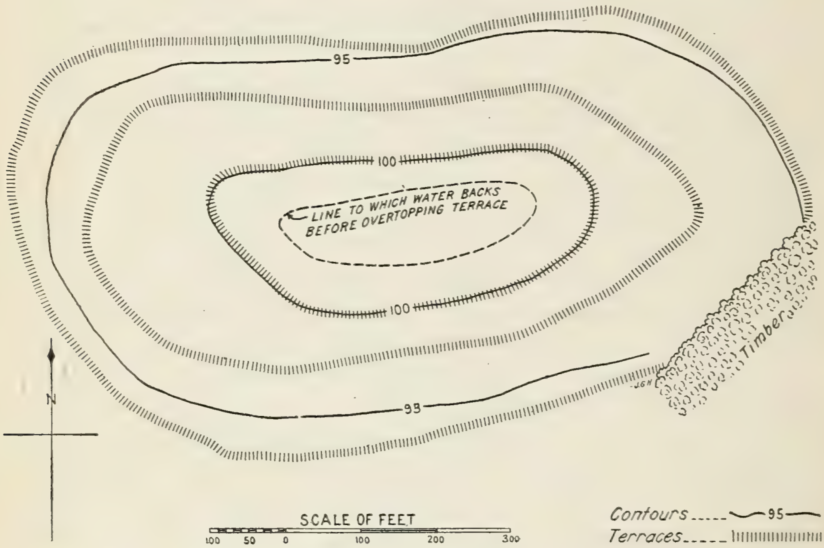


FIG. 6.—Plan of hill protected by broad-base level-ridge terraces.

that provision for 8 inches of rainfall in the design of a system of terraces would give satisfactory results.

By using values of r ranging from 2 inches to 8 inches, depending upon whether a small portion or all of the rain runs off, and using average slopes of land surface of 5, 10, 15, and 20 feet per hundred, a curve for each slope was plotted. (See fig. 7.) The vertical scale on the left of the axis indicates the percentage of an 8-inch rainfall (in 48 hours) that runs off. This percentage depends upon the amount of water absorbed by the soil.

To determine the proper vertical spacing for a system of terraces for any particular field it is necessary to know the average slope of the land surface and the approximate percentage of the rainfall that will percolate into the soil. The former can be measured readily by some form of leveling instrument and the latter can be ascertained

by a knowledge of the physical character, the humus content, and the tillage condition of the soil. The susceptibility of the subsoil to the percolation of water also is an important factor to be considered in estimating the run-off.

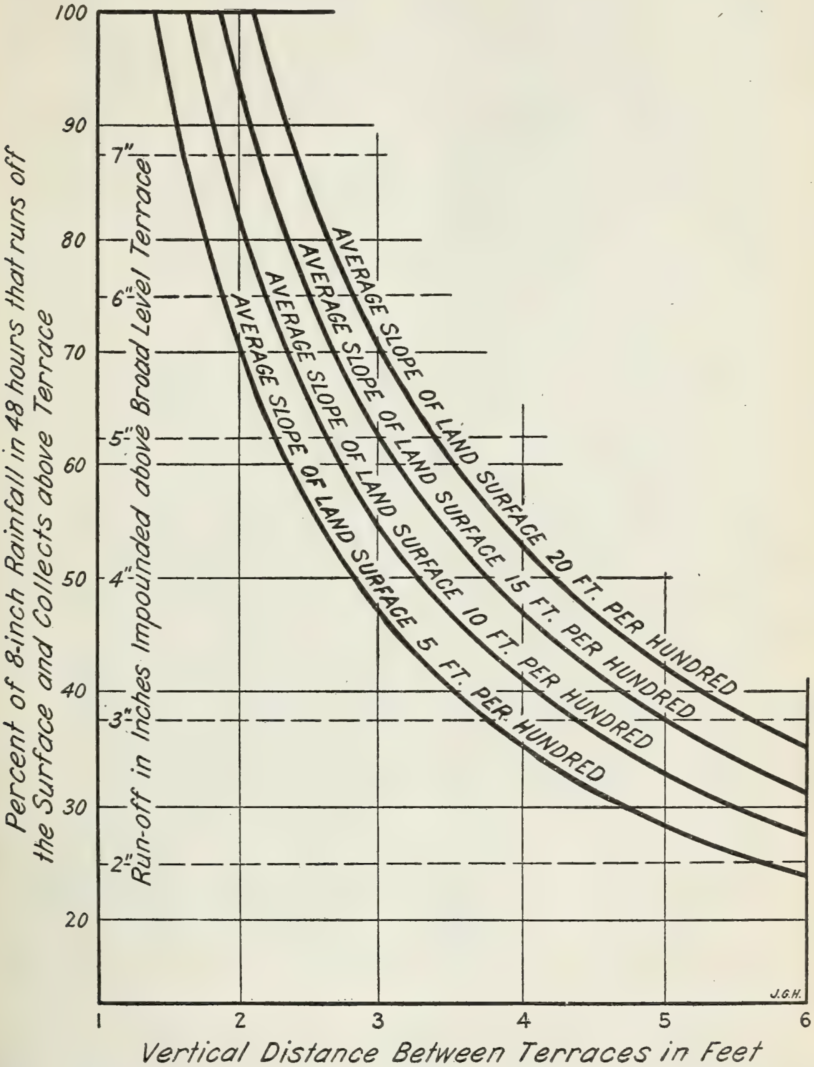


FIG. 7.—Curves showing vertical distances between broad-base level-ridge terraces, for different rates of run-off and land slopes.

It is by no means an easy matter to estimate the percentage of rainfall that will run off for the various types and conditions of soils. For instance, the difference in the rates of percolation for clay and sandy soils is very marked, the latter permitting a much

higher rate than the former. This is due to the fineness of the particles and the compact structure of the clay soils as compared with the open, porous structure and coarse particles of the sandy soils. The open structure of a soil facilitates the entrance and rapid circulation of both air and water, since resistance to flow varies inversely as the size of the individual pore spaces. After a long dry period the pores in the upper layers of a soil become filled with air which, until it is expelled, tends to retard the entrance of soil water. A deeply plowed soil will absorb a greater percentage of rainfall than one where shallow plowing is practiced, and the greater the amount of humus in a soil the greater will be its capacity to absorb water. The rate of absorption after the top soil is saturated with water depends upon the permeability of the subsoil. A close, impervious subsoil checks the rate of percolation and thereby increases the run-off at the surface.

The water capacity of the top foot of farm land in good tilth has been stated[1] to be 4 to 5 inches; thus a soil 12 inches deep could absorb this amount of rainfall provided the rain is supplied to the surface at the same rate at which the soil is capable of receiving it. If the former rate is greater than the latter, the excess water runs off over the land surface with a velocity depending upon the slope. The steeper the slope the more rapid the run-off, and correspondingly less would be the time allowed for the absorption of water by the soil. Hence, the steeper the slope the greater will be the percentage of the rainfall flowing off.

To assist in the determination of the percentage of rainfall flowing off from any particular field, the following table was prepared:

Probable percentages of rainfall running off, for the different types of soil, and for a rainfall of 8 inches in 48 hours.

Kind of soil.	Approximate percentage of silt and clay in the soil.	Run-off expressed in percentage of rainfall.							
		Open, pervious subsoil. Slope of land in feet per hundred—				Impervious subsoil.[1] Slope of land in feet per hundred—			
		5	10	15	20	5	10	15	20
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Sandy	20	40	45	50	55	45	50	55	60
Sandy loam	40	50	55	60	65	55	60	65	70
Clay loam	60	65	70	75	80	70	75	80	85
Clay	80	80	85	90	95	85	90	95	100

[1] The word impervious should be construed to mean that the subsoil admits water but much more slowly than an open, pervious subsoil.

NOTE.—If soil is deeply plowed and contains much humus, deduct 10 from the above values.

[1] U. S. Geological Survey, Water Supply Paper No. 192, p. 315.

The values in the above table are based upon a field study of the effect of soil and slope upon the run-off. A knowledge of the soil, slope and design of several terraced fields which were known to have withstood heavy rainfall successfully for a number of years furnished data from which was estimated the percentage of rainfall that runs off. These figures were used as a basis for interpolating the intermediate values.

The figures given in the above table are to be used in conjunction with the curves in figure 7 to determine the proper vertical spacing of broad-base level-ridge terraces. For example, if it is proposed to terrace a field having an average fall of about 5 feet per hundred, a pervious subsoil, and a deeply plowed clay-loam topsoil containing considerable humus, then the percentage of water flowing off as taken from the table would be 55. This is found by following the space marked "clay loam" to the right until the column headed 5, "slope of land in feet per hundred," under "pervious subsoil," is reached. The value 65 is found at this point. Now the note below the table specifies that 10 should be deducted from the table values for soil deeply plowed and containing much humus. Hence, the value to be used is 65 minus 10, or 55 per cent. To determine the proper vertical spacing from the curves (fig. 7), extend a horizontal line from the ordinate 55 per cent until it intersects the curve marked 5 feet per hundred, and from the point of intersection project a vertical line to the horizontal axis. Such a line intersects the horizontal axis at about 2.6 feet, which is the required vertical distance between terraces.

Where the average slope of a field is less than 5 per cent, use the vertical spacing as obtained from the 5 per cent curve. For intermediate slopes for which no curve is given, the vertical spacing can be obtained by interpolating between the curves plotted. Where the rate of fall of a field varies down a slope, the vertical spacing may be varied between the terraces to suit the slopes. However, a very small portion of a field often has an excessively steep slope as compared with that of the rest of the field. In such cases the vertical spacing should be chosen to suit the lesser and more general slope of the field. This will place the terraces on the steep slope very close together, but it undoubtedly is the most satisfactory solution of the problem.

It can be seen from the curves in figure 7 that the vertical spacing between terraces decreases as the slope decreases, which precludes the possibility of an excessive slope distance between terraces. This relation minimizes erosion between terraces by reducing both the volume of water and the distance traveled by the run-off water from one terrace to another. The horizontal distance between broad-base level-

ridge terraces can be obtained from the curves in figure 4 by adding one-half the vertical distance to the width of the bench for a horizontal-bench terrace.

Were it not for the fact that the terraces would need to be placed very close together on steep slopes, thus necessitating a greater number of terraces, it would be well to reduce the height of the terrace as the slope of the land increases. This would obviate the difficulty encountered in the construction of large terrace embankments on steep slopes.

The equation from which the curves in figure 7 were constructed is based upon the assumption that the ends of the terraces are closed. In the field investigations many terraces with closed ends were found. Some followed contours completely around a knoll or hilltop, forming a closed circuit with no outlet. (See fig. 6.) But most of the level terraces examined had outlets at either one or both ends. In the foregoing discussion the terrace was taken as $1\frac{1}{4}$ feet high; with closed ends it would overflow for a rainfall in excess of 8 inches in 48 hours. However, if one or both ends of a terrace be left open a liberal factor of safety against overflowing is provided. To provide a factor of safety for terraces with closed ends it is recommended that they be made about $1\frac{1}{2}$ feet high.

General discussion.—The success or failure of a broad-base level-ridge terrace depends largely upon whether or not it is laid out on an absolute level. Since the surface of the water stored above the terrace is level, it is imperative that all points along the top of the terrace be above this water level. If one point is low, the water flows over and soon washes away a section of the terrace. All of the water above the terrace then flows toward this crevasse and contributes to the further destruction of the terrace and often erodes a deep gully down through the field. Hence, in laying out a level terrace, the top should be maintained at the same elevation throughout its length.

It is desirable also that the base of the terrace follow the contour of the ground as closely as practicable. This often necessitates the use of very sharp curves and abrupt bends, but it eliminates the existence of any low places or pockets above the terrace which collect and hold water on impervious soil. These sharp bends occur usually at crossings of draws and depressions. Most farmers object to them on account of inconvenience in cultivation and prefer to give the terrace a gradual bend by crossing such places at a lower elevation. Then it is necessary to build the base of the terrace on lower ground and still maintain the top at the same elevation as that of the rest of the terrace, which requires that the terrace be built higher and wider at the base. (See fig. 8.) One landowner who was experienced along this line advised that a terrace crossing a gully or depression be built one-third higher than the required height of the terrace, to provide

against subsequent settling. Examinations of a great number of poorly terraced fields showed that breaks occur usually at such crossings, because of the failure to build the terrace to a sufficient height or to the required breadth at the base.

The advantage of crossing a depression at a low elevation lies in the convenience and facility of cultivation. It eliminates the necessity of following around abrupt bends in farming operations. Some objections to it are the initial cost of constructing the large embankment, the impracticability of cultivating such an embankment, the

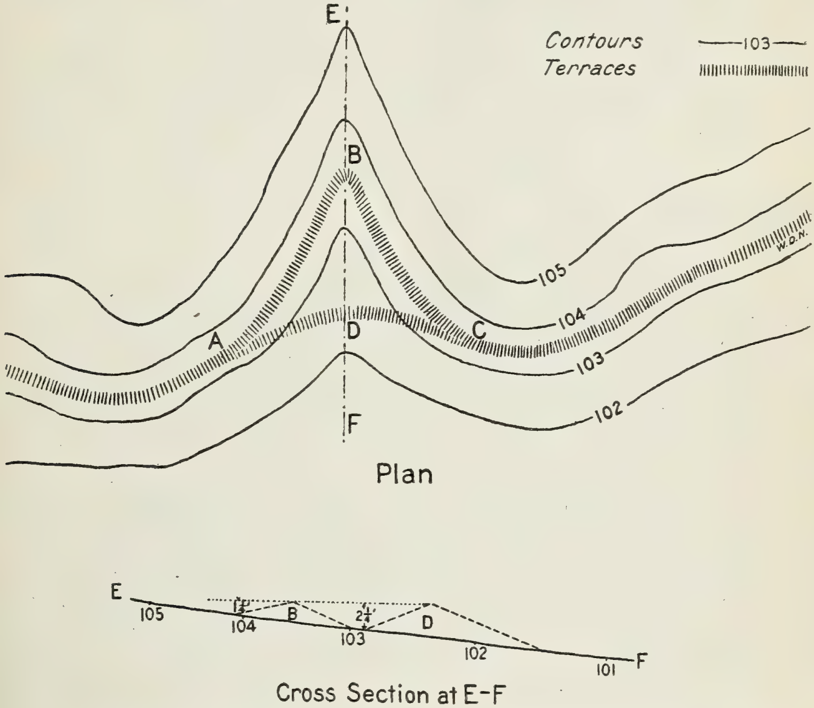


FIG. 8.—Showing two methods of crossing gully. Note height of embankment at D.

extreme susceptibility of this portion of the terrace to failure, and the standing of impounded water above the terrace sufficiently long to injure crops. The disadvantage of the impounded water can be offset by a tile drain laid down the middle of the depression to a natural drainage outlet, and the adoption of this expedient can not be recommended too strongly.

Figure 9 shows a cross section taken down the center line of a depression, or gully, and the method of removing impounded water and retaining sediment by means of a tile drain and drop inlets. If more rapid drainage is desired on a field of level terraces a complete system of tile drains can be installed. The lateral tile drains should

be laid along the upper side of the terrace and made to discharge into the main drain laid down the center of the depression or gully. Where stone is available an inlet may be made by filling a section of the trench to within 1 foot of the surface with loose stones. This will facilitate greatly the entrance of the surface water. This practice can be followed also on the tile lines laid down the gully, thus eliminating the objectionable drop inlets which interfere with farm operations. In addition to removing the surface water through the soil and thereby eliminating surface erosion many other benefits result from the practice of tile drainage.

In planning a system of broad-base level-ridge terraces it is desirable, though not necessary, that the terraces end at natural drainage channels. In the absence of such channels they may end at property lines, fence rows, or timbered areas. Cooperative agree-

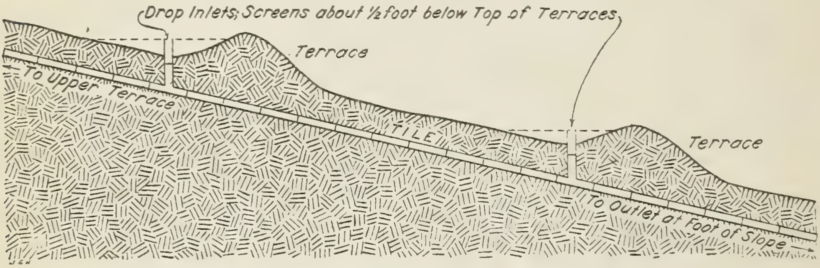


FIG. 9.—Method of removing water impounded behind terraces in a gully.

ments between neighboring landowners for extending a terrace system from one farm to another so that the terraces shall terminate at natural drainage channels would result in increased effectiveness.

Where the system of broad-base level-ridge terracing is employed practically all the fertile particles of soil and the accumulated humus are retained on the surface, and, by proper methods of farming, the fertility of the land is built up from year to year rather than worn out through soil losses. The small amount of soil that moves down the slope, due to such little erosion as takes place between the terraces, can be prevented from accumulating above the terrace by proper methods of plowing and cultivation; that is, by frequently throwing the soil up the slope with the plow and by planting and cultivating the crop rows on level ridges. The result is that each square foot of land surface tends to drink up the maximum amount of the rainfall, and erosive action is thereby reduced to a minimum.

The question arises often as to what becomes of the water above the terrace and whether it remains sufficiently long on the surface to sour the land or injure the growing crop. Experience shows that the natural drainage of open soil on hill lands ordinarily is so rapid that a deficient supply of moisture for crops results and the land is

unable to withstand even a moderate period of drought. The broad-base level-ridge terrace tends to correct this by the detention of water above the terrace.

While most upland soils suffer from a lack of moisture, it is true that "worn-out," impervious clay soils with an impermeable subsoil foundation will not permit a ready percolation of surface water. With such soils the rain water would collect on the surface above the terrace, if pockets exist, and remain sufficiently long to injure plant growth. It is essential in such cases that the ends of the terraces be left open; then if the terraces are laid out absolutely level, the water will flow slowly toward the ends by virtue of the higher elevation of the water surface midway the length of the terrace. The subsoil plow or explosives are used sometimes to loosen up the soil above the terrace and thereby increase the amount of percolation. A complete system of tile drainage, as before mentioned, forms a valuable adjunct to a system of level terraces.

The testimony of a number of farmers experienced in the use of the broad-base level-ridge terrace is, that in dry seasons or periods of drought they obtained the best crop yields from level-terraced fields as compared with adjacent unterraced and graded-terraced lands, and that their crops were equally good in seasons of abundant rainfall.

The broad-base level-ridge terrace is best adapted for use on open, pervious soils and on slopes up to 15 per cent. But it can be used successfully on any type of soil if the vertical spacings are as shown by the curves in figure 7 and means are employed to remove any surface water which may collect in depressions above the terrace. This terrace is used often on slopes steeper than 15 per cent, where such slopes occur in portions of fields having a smaller average slope. Wherever used, it is vitally important that proper methods be employed and care exercised in the laying out, construction, and maintenance of the terrace system.

THE GRADED-RIDGE TERRACE.

The narrow-base form.—Like the level terraces, the first graded terraces were small, with narrow bases, and the terrace embankments were seeded to grass or allowed to grow up in weeds to protect the terrace against erosion due to the flow of the water above. The narrow-base graded-ridge terrace is built usually from 3 to 6 feet wide at the base and from one-half to 1 foot high, with a fall of one-half foot to 2 feet in the 100. Some objections to this terrace are, the necessity of growing a protective covering on the terrace, the erosion along the upper side of the terrace due to the flowing water and the failure of the small terrace embankments to withstand the water pressure above or the effects of erosion due to overtopping.

If the terrace has a fall greater than one-half foot per 100 feet, erosion occurs above the terrace, a channel is scoured out and it develops practically into a hillside ditch. Although this type of terrace is used extensively in the Piedmont region of the South, it is being supplanted rapidly by forms of the broad, cultivated terrace.

The broad-base form.—The broad-base graded terrace, generally known as the Mangum terrace, has been adopted in many sections of the country for the reason that the entire terrace bank can be cultivated—thus utilizing all land and preventing growth of objectionable weeds and grass. This terrace can be crossed readily at any angle in planting and cultivating crops with large farm machinery. When it is intended to use such machinery and to cross at an angle, the terrace must be made broader than when all farming operations are in lines parallel with the terrace. The following tabulated values are the results of surveys of terraced fields of the Mangum type near Wake Forest, N. C.:

Actual dimensions of Mangum broad-base graded terraces.

Dimension.	Absolute minimum.	Absolute maximum.	Field averages.	
			Minimum.	Maximum.
Base width of terrace....feet..	25	50	30	33
Height of terrace....feet..	.3	1	.5	.6
Vertical distance between terraces....feet..	2	8.9	2.8	7.7
Length of terrace....feet..	450	1,250	....	....
Grade of terrace....per cent..	1.69	2.24	2	2.1
Slope of land surface....per cent..	4.7	18.2	5	14

These fields appeared as series of broad waves. On the steepest slopes, where one terrace slope ends the next one begins, the whole field being a succession of terraces. (See fig. 2, E and F.) The rows were run parallel with the terraces shown in figure 2 E; on a less steep slope (fig. 2 F) the rows crossed the terraces.

Surveys were made also of a number of fields with graded terraces where the crop rows always were parallel with the terraces. The results obtained are shown in the following table:

Actual dimensions of broad-base terraces where rows are parallel with terraces.

Dimension.	Absolute minimum.	Absolute maximum.	Field averages.	
			Minimum.	Maximum.
Base width of terrace....feet..	5.2	19	7.8	15.5
Height of terrace....feet..	.4	1.8	.7	1.1
Vertical distance between terraces....feet..	2	9.2	2.9	8.3
Length of terrace....feet..	200	1,800	....	....
Grade of terrace....per cent..	.1	2.24	.3	2
Slope of land surface....per cent..	3.4	20	4.4	14

The width and height of old terraces depend upon their size at the time of construction and methods of plowing employed to maintain them. As a rule terraces that are tended properly grow broader with age and diminish in effective height, so that what is lost in height and diminished size of water channel is gained in broadness, and generally in an increased absorptive capacity of the soil. Graded terraces should be built originally about 10 feet broad at the base and about 1¼ feet high and should be thrown up each year with a plow until they acquire gradually a cross section similar to those shown in figure 2–F.

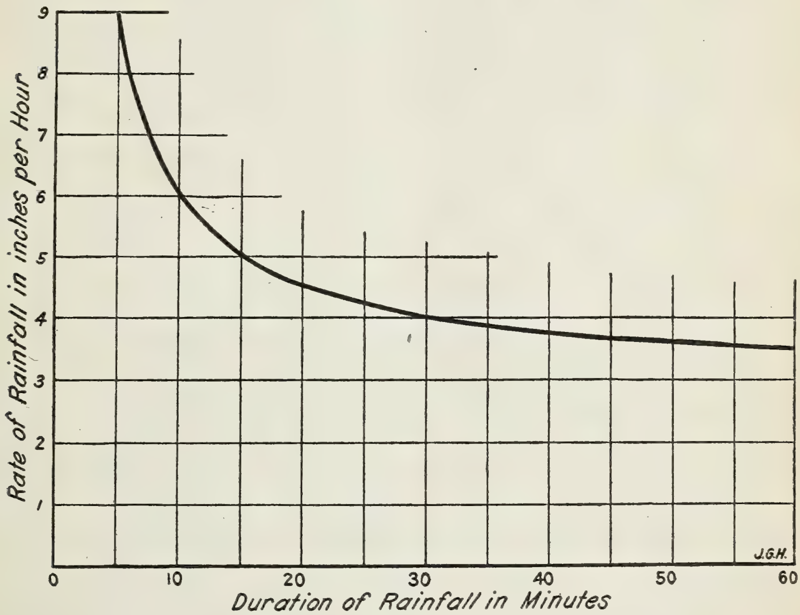


FIG. 10.—Rates of rainfall for short periods, for which graded terraces should be designed.

The principle involved in the design of a graded terrace is that the channel above the terrace be made of such a size and grade that it will conduct the surface water slowly to a drainage outlet without the possibility of the water overtopping the terrace. Hence, it is necessary to know something of the rates and duration of the rainfall which is the source of the surface water.

A study was made of rainfall intensities for short periods, as shown by the Weather Bureau records for the humid portions of the United States, and a curve (fig. 10) was plotted which is thought to represent closely the rates of rainfall for short periods that should be provided for in the design of a system of graded terraces. The records show that these rates sometimes will be exceeded, but not so frequently in any given locality as to warrant

greater rates being used. Referring to the curve, the horizontal scale represents the durations of rainfall in minutes and the vertical scale the rates of rainfall in inches per hour. For example, from the curve the rate of rainfall for a rain lasting 30 minutes would be 4 inches per hour, and one of 5 minutes 9 inches per hour. The equation for this curve is:

$$y=\frac{30}{x}+3$$

where y = rate of rainfall in inches per hour, and x = duration of rainfall in minutes.

To determine the rate of discharge to be provided for in the design of a terrace system, the so-called rational method of computing run-off is employed. According to this method the maximum discharge will take place when water from the most remote point of the drainage area above the terrace reaches the terrace outlet, provided the rate of rainfall continue uniform for a period equal to that required for water to travel from the upper to the lower end of the drainage area. Hence if the length and grade of the terrace be known and the average velocity of flow be computed, the time interval can be obtained readily. For instance, if the time interval is found to be 30 minutes, then the maximum rate of rainfall to be expected would, from the curve, be 4 inches per hour. In computing this time interval the distance from the upper to the lower end of the drainage area is taken as being equal to the length of the terrace, the distance between terraces being disregarded. This practice results in the use of a little larger rate of run-off than would apply if the distance between terraces were included and therefore is on the side of safety. Furthermore, the velocity at the lower end of the terrace, instead of the average velocity along the terrace, was used in computing the time interval which likewise would result in the use of a little larger rate of run-off.

Terraces with uniform grade.—Field examinations of a great many graded terraces show that erosion of average soils takes place where the grade of the terrace exceeds 0.5 foot per 100 feet. Even at this grade some of the fine particles of soil are carried away in the run-off water. Many advocates of the graded terrace favor the use of a grade not to exceed 0.5 per cent. The following values were used in the computations for the curves discussed hereafter: Base width of terrace, 10 feet; height of terrace, 1¼ feet; depth of flow, ¾ foot; and value of "n" in Kutter's formula, 0.035. Using the velocity computed by the formula, $v=c\sqrt{rs}$, where c is the constant determined from Kutter's formula, r the hydraulic radius, and s the slope, the time intervals were determined for terraces ranging in length from 300 to 1,800 feet. The corresponding rates of rainfall

were obtained for these time intervals from the rainfall curve in figure 10; these are the rates of run-off that would obtain at the lower ends of the terraces, assuming all the rainfall to run off. With the above data the required vertical distances between terraces of different lengths were computed and the curves in figure 11 plotted. Two factors of safety are included in the above computations, (1) the depth of flow is made only ¾ foot, whereas the terrace is built 1¼ feet high, and (2) all of the rainfall is assumed to run off, whereas a portion of it would percolate into the soil. Experience shows that a wide margin of safety is most desirable owing to the piling up of the water due to obstructions or abrupt bends, and to possible variations in the height of the terrace and in the grade.

To illustrate the use of the curves in figure 11, suppose it is desired to determine the proper vertical spacing on a field with a slope of 15

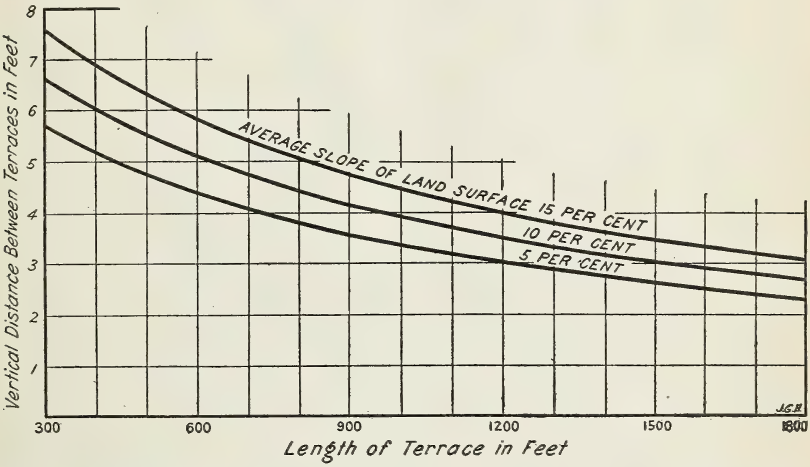


FIG. 11.—Uniform-graded terraces, for grade of 0.5 per cent. Curves showing required vertical distances between terraces for different land slopes and terrace lengths.

per cent for terraces 600, 700, 800, and 900 feet in length. Referring to the curve marked 15 per cent in figure 11, it is seen that the proper vertical spacings for terraces of these lengths are about 5.8, 5.4, 5.1, and 4.7 feet, respectively. It will be seen from the curves that the longer the terrace the less must be the vertical spacing. Owing to this fact and to the greater likelihood of breaks in a long terrace, it is advisable to make the terraces as short as the governing conditions will permit. Where an adequate outlet is available at both ends of the terrace, they should be utilized by giving fall to the terrace from about the middle toward each end. For terraces less than 300 feet in length the same vertical spacing should be used as is given by the curves for 300 feet.

If it is desired to maintain the same vertical spacing for all lengths of graded terraces, it becomes necessary to increase the grade

for the longer terraces, since the drainage area increases with the length of the terrace while the cross-sectional area of the channel remains constant. Field observations show that spacings of 3, 4, and 5 feet give the most satisfactory results on slopes of 5, 10, and 15 per cent, respectively. Using these data, the three curves in figure 12 were plotted. It can be seen from these curves that for a given vertical spacing and land slope, the grade required increases rapidly as the length of the terrace increases, and if it were not desired to use

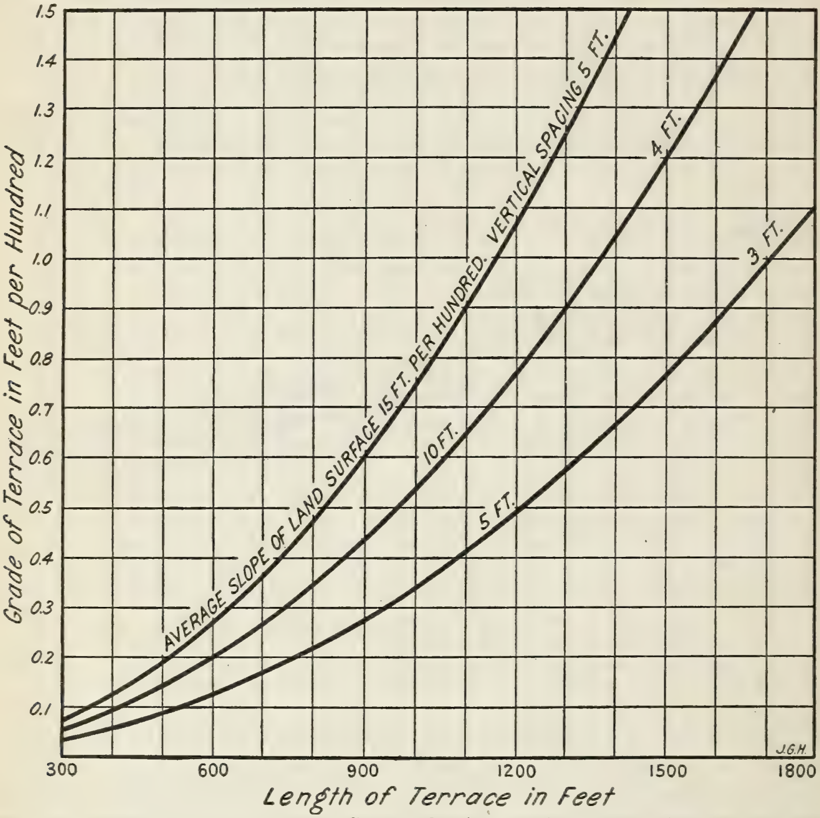


FIG. 12.—Uniform-graded terraces. Curves showing required grades for different land slopes, terrace lengths, and vertical spacings.

a grade greater than 0.5 per cent the lengths of the terraces on the 5, 10, and 15 per cent slopes would be limited to 1,210, 970, and 820 feet, respectively. The curves show also that terraces up to 300 feet in length require very little grade. A terrace of only 300 feet requires practically no grade on any type of soil, because a sufficient grade will be created by the distribution of water above the terrace to cause a flow toward the ends. Other things being equal, the most efficient terracing is found where comparatively short terraces and low grades exist.

For this type of terrace it would not be necessary to maintain the same size of embankment throughout the length of the terrace, but the embankment could be reduced as the upper end is approached. The channel capacity required, which depends upon the drainage area above, decreases toward the upper end of a uniform graded terrace.

Terraces with variable grade.—Surveys were made of several fields with graded terraces where the grades were found to vary. These were in better condition than were any having uniform-graded terraces. The profiles of the grade lines of these terraces showed a tendency of the grade to increase toward the outlets, a short distance at the upper end of the terrace being level. This practice possesses much merit. The grade is increased at intervals along the terrace to accommodate the continually augmented discharge from the increasing size of the drainage area. A lesser grade may be used at the lower end of a variable-graded terrace than is required for a uniform-graded terrace of the same length. This is due to the fact that a smaller rate of rainfall can be used, since with the lesser grade of the variable-graded terrace, the time required for the water to flow the length of the terrace is greater than for the uniform-graded terrace.

In figure 13 are shown curves for terraces with variable grades, similar to the ones in figure 12 for terraces with uniform grades. It can be seen from the curves that the lengths of a variable-graded terrace that can be used, for a grade of 0.5 per cent at the lower end, are 1,570, 1,280, and 1,100 feet on slopes of 5, 10, and 15 per cent, respectively, as compared with lengths of 1,210, 970, and 820 feet for terraces with a uniform grade of 0.5 per cent.

In laying off a terrace with variable grade, the grade should be increased at intervals of 200 or 300 feet and at all sharp bends where the terrace crosses a gully or depression in a field. For example, if it is desired to lay off a terrace on a 10 per cent slope, 1,200 feet long and with a vertical spacing of 4 feet, and the grade of the terrace is to be changed every 300 feet, then from the curves in figure 13 the grades would be as follows:

Station.		Grade in feet per 100 feet.
From—	To—	
0	300	0.05
300	600	.14
600	900	.27
900	1,200	.45

It is seen from the above that the grade for the first 300 feet of terrace is almost negligible. This portion could well be laid off

level. If a terrace with a uniform grade were used, the curve in figure 12 shows that a grade of 0.77 per cent would be required. Both practice and theory show that the variable-graded terrace is superior to the uniform-graded type.

Outlets.—Wherever possible terraces should end at natural drainage channels. The absence of a suitable drainage outlet within the limits of a field often necessitates ending the terraces at fence lines, depressions or draws. The volume of water which is discharged from the ends of a system of graded terraces often erodes unsightly and objectionable ditches along the ends of the terraces to the foot

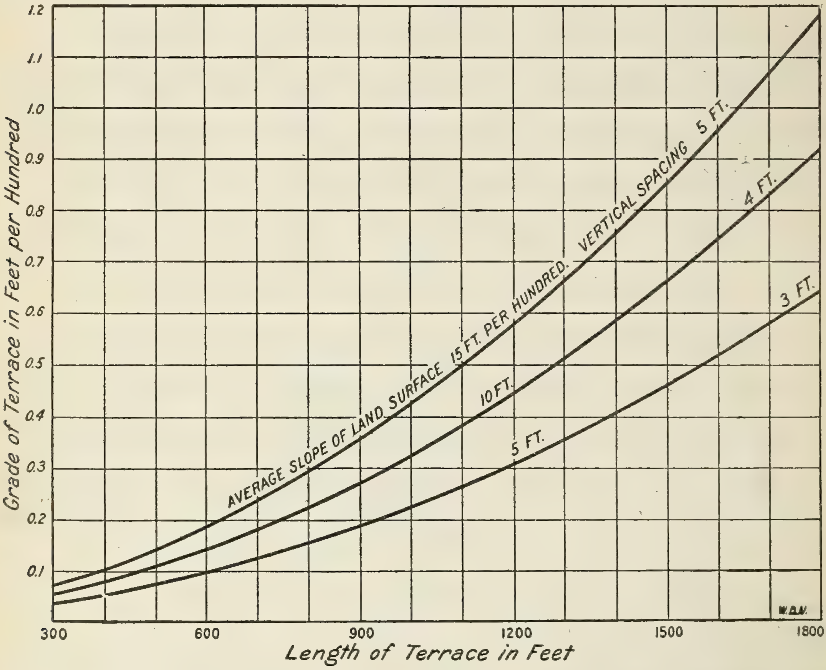


FIG. 13.—Variable-graded terraces. Curves showing required grades for different land slopes, terrace lengths, and vertical spacings.

of the slope. Erosion in such channels can be reduced greatly by lining them with stones or seeding them to grass (see Plate V, fig. 2). The channels and banks of graded terraces should not be cultivated for 20 to 30 feet from the outlet channel but should be permanently sodded. Breaks commonly occur and erosion is most active near the ends of graded terraces, owing to the usually large volume of water passing. Some sort of protective covering of stones, boards or other hard material should be employed to prevent this washing. Where a terrace discharges into a deep ditch a box trough is used sometimes to give the water a free overfall into the ditch. This prevents erosion in the terrace channel.

D659

FIG. 1.—VIEW SHOWING GRADED TERRACE WASHING BADLY DUE TO EROSIVE ACTION OF WATER.

D187

FIG. 2.—TERRACE DRAG WITH METAL CUTTING EDGE FOR BUILDING UP TERRACES.

D191

FIG. 1.—TERRACE DRAG (LONG SIDE HINGED) FOR BUILDING UP TERRACES.

D658

FIG. 2.—GRADED TERRACE CONSTRUCTED WITH PLOW AND SCRAPER.

Sometimes hillside ditches are constructed as outlets for terraces. Such ditches should have a fall two or three times that of the terraces and should be located so as to cross them and discharge into the nearest available drainage channel. Often wooded strips of land are left in fields to afford a place for the discharge of the water with a minimum amount of erosion.

General discussion.—Many of the failures of graded terraces may be attributed to irregularities in grade. Breaks occur often with abrupt reductions in the grade. This causes a piling up of the water and a consequent overtopping of the terrace by reason of the inability of a full channel to carry the same amount of water on a light grade as on a heavy one. With a variable-graded terrace there is less likelihood of overtopping because the grade is increased at short intervals along the terrace.

Again, breaks in graded terraces are very frequent where gullies and depressions are crossed and at abrupt bends. Such breaks are due to sudden changes in the direction of flow or to a change in grade, and often to both. The usual practice of crossing depressions at a low elevation to avoid abrupt bends, as explained under "The broad-base level-ridge terrace," results in an increase of grade to the middle of the depression and a decrease beyond the middle. In order to avoid a break due to this diminution in grade it becomes necessary to maintain the top of the terrace at a uniform grade. This necessitates the building of a high and broad embankment across the depression similar to the one described for level terraces. Wherever it can be done without increasing the grade to such an extent as to cause serious erosion, it is advisable to make the grade greater for that portion of the terrace leading away from the middle of the depression than for the portion leading to the middle.

The graded terrace is adapted particularly for use on impervious and worn-out soils, and on shallow open soils with an impermeable subsoil foundation—in general, soils that are incapable of absorbing much water. Since the object of terracing is to prevent erosion, and as this is accomplished best by securing the least movement of the surface water, it can be seen readily that, within limits, the efficiency of a graded terrace varies inversely with the amount of fall given to it. The greater the fall the greater the velocity and, hence, the greater the erosive power of the moving water.

The embankment of a graded terrace, being subjected to the erosive action of the water on its upper side, is often washed considerably, particularly at bends. Plate VI, fig. 1, shows a graded terrace embankment cut away practically half by erosion and the heavier parts of the soil deposited along the upper side of the terrace. The deposit of soil in the terrace channel reduces both the grade and the cross-sectional area of the channel and renders the terrace extremely

susceptible to overtopping during the next rain. Also the finer, lighter, and more fertile particles of soil remain suspended in the moving water and are carried off the field. In such cases, by the use of excessive grades, the very cream of the soil is lost. Where erosion of a terrace takes place no attempt should be made to cultivate the terrace. It should be seeded to grass.

COMPARISON OF TERRACE TYPES.

In order to show the relative merits of the bench terrace and the various forms of broad-base ridge terraces, the table below was prepared. Under the column headed "Least amount of erosion" is found the broad-base level-ridge terrace ranking first and the uniform-graded terrace last. Since the primary object of terracing is to reduce erosion, this advantage should have the greatest weight when considering the merits of the different types. The broad-ridge terrace is much superior to the bench type of terrace when considering the "Least waste land or weeds." The embankment of broad-ridge terraces can be cultivated successfully and hence no land is lost to cultivation or weeds allowed to grow on the terrace.

Showing how terraces rank with respect to various advantages.

Type of terrace.	Least amount of erosion.	Least waste land or weeds.	Fewest terraces required in field.	Ease of cultivating land.	Best adapted to— Pervious soils.[1]	Best adapted to— Impervious soils.	Best adapted to— Steep slopes.	Best land builder.
Horizontal and sloping bench	2	2	3	2	2	3	1	2
Broad-base level ridge	1	1	3	1	1	4	4	1
Broad-base uniform-graded ridge	4	1	2	1	4	2	3	4
Broad-base variable-graded ridge	3	1	1	1	3	1	2	3

[1] With reference to least amount of erosion.

Under the column headed "Fewest terraces required in field," the graded terrace ranks ahead of the level type owing to the fact that by giving the terraces considerable fall they may be spaced farther apart than level terraces. However, the greater vertical spacing can be used only at a cost of greater erosion to the field.

Broad-terraced fields are easier to cultivate than the bench type since implements and large machinery can be moved across the broad terraces and if desirable the rows can be run at any angle. With the bench type each bench must be cultivated separately, and difficulty is encountered in getting implements from one bench to another.

From the standpoint of erosion the broad-base level-ridge terrace is best adapted for use on pervious soils; on impervious soils the graded terrace can be used to the best advantage since in the former case most of the water is drained off through the soil and in the latter the water is drained off the field over the surface.

The bench terrace is best adapted for use on steep slopes where it would be practically impossible to build and cultivate a broad-ridge terrace.

The broad-base level-ridge terrace contributes to the building up of land possibly more than does any other form. With this terrace practically no fertile parts of the soil are allowed to escape from the field. The bench terrace also is a good land builder. The greatest objection to the use of the graded terrace is that the water drained off the field usually carries in suspension fertile particles of the soil.

The table below was prepared to assist in the selection of the terrace best adapted to the needs of a particular field. In this connection it is recommended that the design of the terrace system be made from the curves as given in this paper for each type of terrace.

Types of terraces most applicable to land of various slopes.

Kind of terrace.	Average slope of land.	Type of soil.	Grade of terrace.
	Per cent.		
Horizontal and sloping bench	15 to 20	Fairly pervious.	Level.
Broad-base level ridge	3 to 15	do	Do.
Broad-base graded ridge	3 to 15	Impervious, worn out.	Preferably variable, 0.0 to 0.5 per cent.[1]
Broad-base level ridge with tile drainage	3 to 15	Any type	Level.

[1] Grade will depend upon the length of the terrace, but it is advisable not to exceed a grade of 0.5 per cent if possible.

On the steeper slopes, where the soil erodes easily, clean-cultivated crops, such as cotton and corn, should not be grown. Impervious soils on slopes of 15 per cent or more, and all soils on slopes of more than 20 per cent, are best suited to pasture and timber.

The result that should be attained by a system of terraces and proper farming methods is well expressed in the following quotation taken from a bulletin[1] on Soil Erosion by W J McGee, of the Bureau of Soils, United States Department of Agriculture:

> The primary object is conservation of both solid and fluid parts of the soil through a balanced distribution of the water supply. The ideal distribution is attained when all the rainfall or melting snow is absorbed by the ground or its cover, leaving none to run off over the surface of the field or pasture; in which case the water so absorbed is retained in the soil and subsoil until utilized largely or wholly in the making of useful crops while any excess either remains in the deeper subsoil and rocks as ground water or through seepage feeds the permanent streams.

The above conditions are fulfilled most nearly by the horizontal bench terrace and the broad-base level-ridge terrace, since the movement of the water is reduced to a minimum by both. The graded terrace lacks much in meeting the requirements. The broad-base

[1] U. S. Dept. of Agr., Bureau of Soils, Bulletin 71, p. 56.

level-ridge terrace possesses a decided advantage over the horizontal bench terrace with respect to the elimination of weeds and waste land, and over the graded terrace with reference to the movement of the surface water.

In view of the above discussion it is recommended that the broad-base level-ridge terrace be used wherever conditions of soil and topography will permit—that is, where the soil absorbs a portion of the rainfall and the slopes are not too steep. The broad-base level-ridge terrace supplemented by efficient tile drains suitably located would afford the most ideal method for preventing soil erosion on any type of soil. Often the yields obtained and the saving resulting from the absence of soil erosion would justify, in a financial way, the installation of tile.

LAYING OFF A TERRACE SYSTEM.

The courses to be followed by the terrace lines are governed by the topography of the field. This is well illustrated in figures 14 to 16. Where the slope of a field is practically uniform and in one direction (fig. 14) the terrace lines will be straighter and more regular than where the slopes vary much in amount and direction (figs. 15 and 16). Figures 14 and 15 show fields having broad-base level-ridge terraces. It will be noted that the terraces follow approximately the contours of the ground. Figure 16 illustrates a field of broad-base graded-ridge terraces. In this case the terraces are seen to cross the contours.

It must be remembered that a terrace is designed to provide for the run-off water from a limited area above it and when this area is exceeded the stability of the terrace is endangered. A very common cause of failure of terrace systems is the fact that the upper terrace in the field is made to drain an excessive area. As a result, the upper terrace breaks, and a large volume of water rushes down the slope, breaking all terraces below. Frequently a farmer desires to terrace his farm but his neighbor's farm lies at a higher elevation and the upper terrace would be required to handle run-off water from his neighbor's land. In such cases an attempt should be made to induce the neighbor to terrace his farm also. If this can not be done the water from above must be intercepted by means of a hillside ditch to carry the water to the nearest drainage channel below.

The success or failure of a terrace system is largely a matter of proper laying off of terrace lines. Various kinds of homemade devices are employed for laying off terraces, but unless the operator exercises special care in the use of them the results usually are poor. Many landowners realize the inefficiency of these devices and have adopted as a substitute a cheap form of telescopic spirit level mounted on a tripod. Even with this level, in the hands of an

inexperienced or careless operator, the results obtained are far from satisfactory. Surveys of seven level-terraced fields where a level of the above type was used showed an average variation in level along the terraces for each field ranging from 0.4 to 2.6 feet. The engineer's Y level is by far the most satisfactory instrument for this work and the results obtained warrant the small expense of employing a competent engineer or surveyor who has such an instrument. A number of surveys of terraced fields laid off with an engineer's level in the hands of experienced levelmen showed remarkably little variation from the level or uniform grade line.

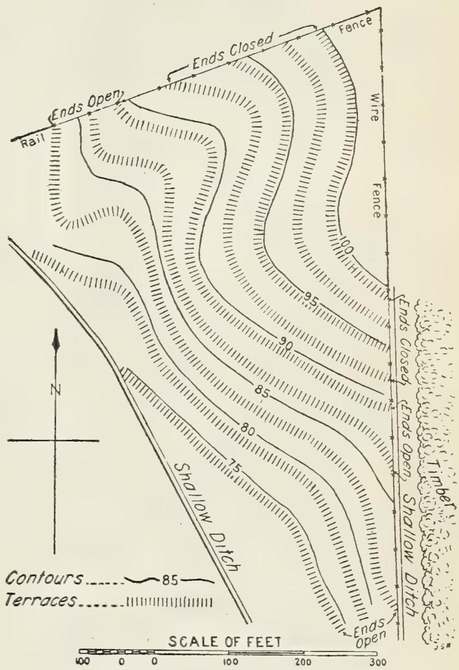


FIG. 14.—System of level-ridge terraces on a field having regular slopes.

Laying off level-terrace lines is a simple leveling proposition which consists merely of following contours of the field with a chosen vertical interval between them. The terrace nearest the top of the field should be laid off first. The level instrument should be set in a position near the middle of the terrace line so as to command a view of the whole length of the terrace, and sufficiently high so that the bottom of the rod, when set at the highest point in the field, is slightly below the level line of sight of the instrument. If, for instance, the reading observed on the rod at the highest point be 0.5 foot and the vertical distance between terraces is to be 3 feet, the rod is placed at a point directly down the slope where the rod reading is 3.5 feet. To establish the line of the terrace, points of equal elevation should then be located to both ends of the terrace at intervals of 25 to 50 feet, the closer spacing being used for land of irregular topography. Invariably a point should be established where the terrace line crosses a draw, gully, or depression. The points established may be marked permanently by stakes to be used subsequently as guides in the construction of the terrace. A very common method is to lay out and construct the terrace at the same time, or at least to plow one furrow to establish definitely the line of the terrace. In this method the rodman is followed by a man with

a hoe who digs a hole at each position of the rod to serve as guides to the plowman who follows immediately and lays out the first furrow. This is the cheapest and most satisfactory method of laying out level terraces.

Several terraces may be laid out from one position of the instrument, depending upon the vertical interval and length of the rod. If the entire length of the terrace can not be seen from one position of the level, the rodman should retain the rod at the last point visible, the instrument should be moved to a new position, and a reading of the rod taken. This reading should be used in locating points on the terrace line from the new position of the instrument.

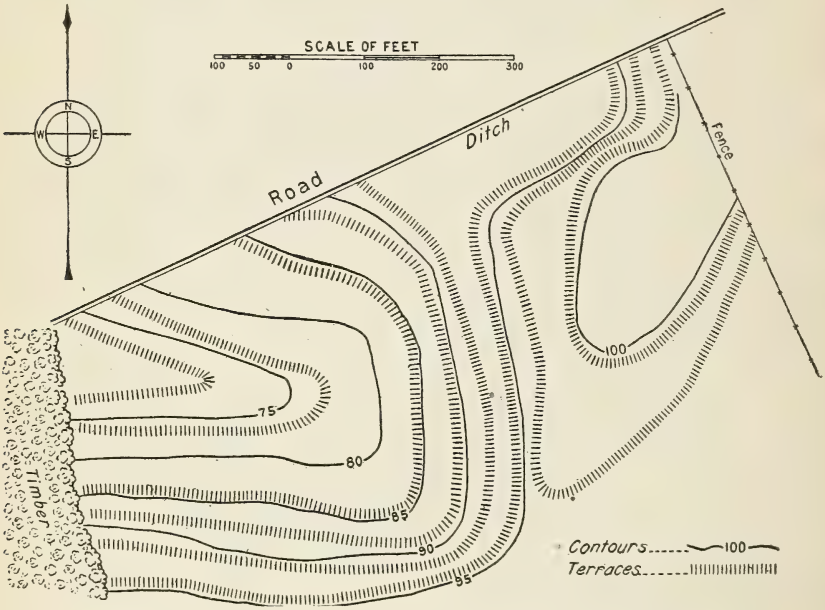


FIG. 15.—System of level-ridge terraces on a field having irregular slopes.

The graded terrace is more difficult to lay out than is the level terrace, because the rod readings never are the same for any two points on the terrace line. The first point on the terrace line is found in a manner similar to that described for the level terrace. Assuming that the terrace drains to one outlet, then a fall will occur from the middle of the terrace line toward the outlet and a rise in the other direction. If, for instance, a grade of 0.4 foot per hundred feet be used, and if guide stakes are to be set 50 feet apart where the alignment is fairly straight and 25 feet apart on bends, then for each 25 feet in distance toward the outlet a fall of 0.1 foot would be required, and, therefore, for each 25 feet in the direction of the outlet the rod reading should be increased 0.1 foot. The distance should be measured with a tape. If a variable grade is used the rod readings should be computed accordingly.

No attempt is made to give comprehensive instructions for laying out terraces since different topographical conditions will suggest different methods of procedure to the levelman of good judgment and experience. The best results are obtained with a good leveling instrument in the hands of a careful, competent, and experienced levelman.

CONSTRUCTION OF TERRACES.

All types of terraces are constructed originally in the same way. The work of construction should begin invariably with the highest terrace in the field and each terrace should be completed before work

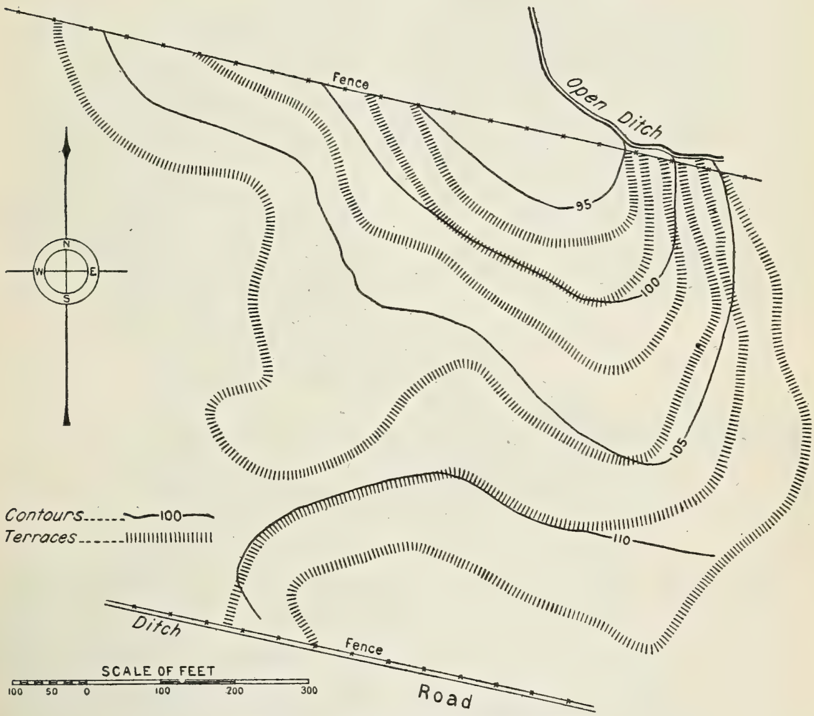


FIG. 16.—Field of graded-ridge terraces.

is started on the one next below. The late fall and early winter is the best time to lay out and build terraces. If one has not time to terrace his whole field well it is better to construct well the first few terraces near the upper side of the field than to terrace the whole field poorly, for a break in a terrace near the upper side of the field is followed by breaks in all below.

The terrace embankment can be built up wholly with an ordinary turning plow. A large sixteen-inch plow with an extra large wing attached to the moldboard for elevating the dirt, is an effective implement for throwing up a high terrace bank. For broad terraces furrows are thrown toward the center line from each side for a strip

15 to 20 feet in width. Then, commencing at the center again, the strip is plowed in the same manner as before. This procedure is repeated until the terrace has reached the desired height. Many farmers allow the loose earth to be settled by a rain between plowings so that the dirt will turn better. However, it is safer to build the terrace to the desired height at the start for, if a heavy rain, sufficient to overtop the terrace, comes between plowings, much of the original work is undone and considerable damage occurs from erosion. A disk plow can be used successfully to throw up loose dirt, and the ordinary road grader is employed often and is adapted especially to such work.

The most commonly used and cheapest implement for throwing up a terrace is a wooden, V-shaped drag. Plate VI, figure 2, and Plate VII, figure 1, show two terrace drags that have been used satisfactorily. Figure 17 shows a terrace drag with dimensions.

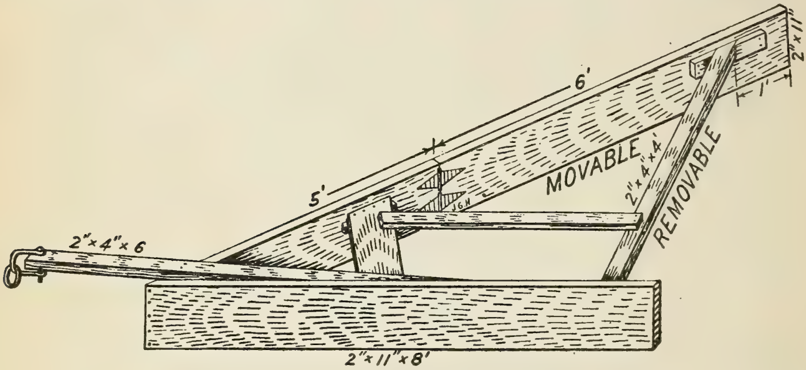


FIG. 17.—A terrace drag.

After the first three or four furrows have been plowed on each side of the center line of the terrace, the drag is used to push the loose earth toward the center and thus build the terrace higher. The plowing is resumed and the drag used again, and this is done repeatedly until the terrace has attained the desired width. If the terrace is not built sufficiently high the first time, the work is started again at the center and the plowing and dragging are repeated. The longer side of the drag is hinged so that for the first few furrows the hinged portion is allowed to swing loose. As the terrace increases in width, and it is desired to move the loose earth a greater distance, the removable brace is set in position and the hinged portion is brought into use. The short side of the drag is made to follow the open furrow; this holds the drag in the proper position. The piece to which the hitch is made should be set at a vertical angle with the shorter side, as shown in figure 17, and also at a horizontal angle, as shown in Plate VII, figure 1. The former tends to keep the short side parallel with the bottom of the furrow and the latter

D661

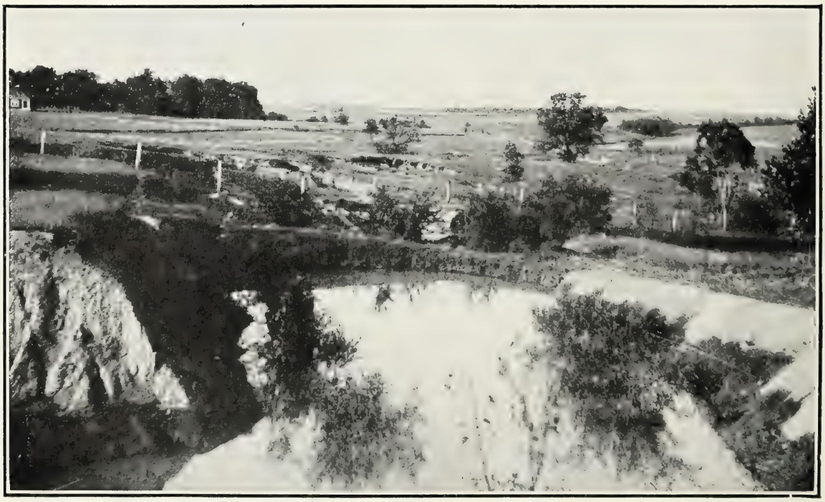
FIG. 1.—ROW OF COTTON ON TOP OF BROAD-BASE LEVEL-RIDGE TERRACE.

D662

FIG. 2.—THREE ROWS OF COTTON ON BROAD-BASE LEVEL-RIDGE TERRACE.

D184

FIG. 1.—BADLY ERODED LAND NEAR HOLLY SPRINGS, MISS., THAT WAS MADE TO PRODUCE CROPS.



D182

FIG. 2.—DAM-AND-POND METHOD OF RECLAIMING GULLIES.

keeps the point pressing slightly against the edge of the furrow and prevents a tendency of the drag to jump out.

Graded terraces commonly are built with a plow and drag scraper. A strip is plowed, as heretofore described, and the loose earth on the upper half of the strip is scraped up and deposited on the lower half. By this method a channel is constructed for the flow of the water, and the earth used to build up the embankment. (See Pl. VII, fig. 2.)

MAINTENANCE AND CULTIVATION OF TERRACES.

A newly built terrace is susceptible to failure until it becomes thoroughly settled. For this reason it is not advisable to cultivate the terrace the first year. It should be sown to some sort of cover crop. Breaks in terraces in the first year tend to discourage a novice in the use of terraces, but unless the embankment is built to an abnormally large size breaks occur often in newly made terraces.

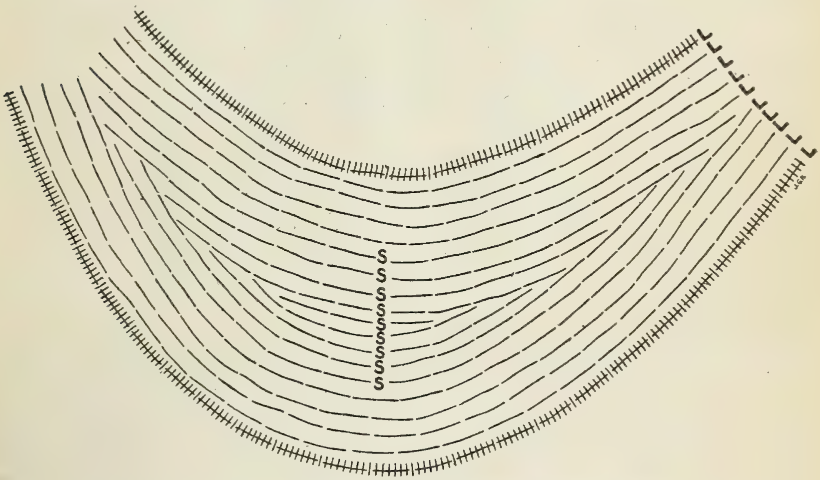


Fig. 18.—Method of laying out rows where distance between terraces varies (L, long rows; S, short rows).

After the terrace has been established permanently, the soil should be thrown toward the center at each plowing of the field, at least once a year. This will increase the breadth and maintain the height of the terrace and the field eventually will assume an appearance of a succession of prominent waves, all of which may be cultivated easily. (See fig. 2–D, E, and F.)

In cultivating a terrace as much of the soil as possible should be thrown toward its center. The best results are obtained where the rows are run parallel with the terraces. At first, usually one row is planted on the top (Pl. VIII, fig. 1), but as the terrace grows broader several rows are planted as shown in Plate VIII, figure 2. These rows invariably produce a greater yield than do those on the land

between the terraces. Where large machinery is used, and it is difficult to follow the terrace line, the rows may be run at an angle across the terraces, where the land is not very steep, as in figure 2–F. To do this the terraces must be broad and must be thrown up at least once a year to maintain their height.

Where the rows between two adjacent terraces are to be laid out parallel with the terraces, the same number of rows should be run parallel with each terrace as indicated by the rows marked "L" in figure 18. Owing to the variation in distance between terraces it then will be necessary to fill in with short rows, generally known as "point rows." These rows, marked "S" in figure 18, are run in pairs so as to facilitate the work of cultivation.

RECLAMATION OF GULLIED LANDS.

The best results accomplished in the reclamation of badly gullied and eroded lands were found on the State agricultural experiment farm near Holly Springs, Miss. Plate IX, fig. 1, shows an extreme type of land that was completely reclaimed and made to produce crops. The gullies were partially filled by plowing the soil into them from along the edges, and further filled and levelled off by means of teams and scrapers. As soon as possible a sod of lespedeza or Bermuda grass was started over the levelled-off eroded areas. Most of the land was terraced with broad-base graded-ridge terraces, and terraces, or dams, were constructed across gullies that were too large and deep to be economically reclaimed by filling in. Ponds formed above these dams (see Pl. IX, fig. 2) which served to catch all soil carried into them from above.

Gullying can be effectively checked also by planting trees in the depressions. The native pine and black locust are recommended. Filling in gullies with straw and brush also checks erosion. In one instance a gully was practically reclaimed by dynamiting the bottom to loosen the soil and then stretching wire netting across the gulley below to catch soil particles and vegetation. The use of large pipe through a dam, with a drop drain above, is also a method which can be used effectively.

SUMMARY.

To soil erosion may be attributed the existence of much of the "worn-out" hill lands of the United States. Erosion can be controlled most effectively by the use of terraces. Although terracing is now quite widely practiced in the Piedmont region of the South, in only a few sections are efficient results being obtained. Since the comparatively few well-designed and constructed terrace systems are uniformly successful in preventing soil wash, it follows that the many failures must be ascribed to unsuitable design, faulty construction, or lack of proper maintenance.

The terraces in use in this country are of two general classes, the bench terrace and the ridge terrace, each having variations which are adapted to particular conditions of topography and soil.

The true horizontal-bench terrace is not used widely in the United States, while the sloping-bench terrace is quite common. The disadvantages of the bench terrace are that it can not be crossed by modern farm machinery; the banks can not be cultivated, while each bench must be cultivated as a separate field; weeds and objectionable grasses which grow on the banks tend to sow the entire field. It is best adapted to slopes too steep to permit the use of any form of cultivated terrace, but it can not be recommended for use on slopes exceeding 20 per cent.

The narrow-base level-ridge terrace is used extensively in the Piedmont section of the South. It is cheap to construct and easy to maintain. However, attempts to cultivate this type of terrace have not been successful generally; consequently, as in the case of the bench terrace, considerable land is lost to cultivation, and the growth of weeds and grasses on the embankments tends to seed the entire field as well as sap the strength of the adjacent soil. Outside of these objections, the narrow-base level-ridge terrace, where heavily sodded, renders satisfactory service on pervious soils and slopes not greater than 8 per cent.

The broad-base level-ridge terrace has been developed from attempts to render cultivable the narrow-base form. It has all the advantages of the latter terrace with the added one that no land is lost to cultivation. By the use of this terrace little or no soil is removed from the field. It is best adapted to use on open, pervious soils on slopes not exceeding 15 per cent, but under proper conditions of design, construction, and maintenance can be used on any soil and on slopes somewhat greater than 15 per cent.

As in the case of the level-ridge terrace, the first graded-ridge terraces were small with narrow bases, and they are subject to the same objections that apply to the narrow-base level-ridge type. Moreover, the velocity of flow of the water, due to the grade of the terrace, tends to erode the upper side of the embankment to an extent which a narrow-base terrace can not withstand.

The broad-base graded-ridge terrace (the Mangum terrace) has been adopted in many parts of the country. This terrace, properly constructed, not only can be cultivated but it can be crossed at any angle with large farm machinery. Its broad base and flat embankment slopes render it less liable to damage by the flowing water than is the case with the narrow-base type. The grade may be either uniform or variable, but both practice and theory indicate the variable-graded terrace to be superior to the uniform-graded type.

The graded terrace is adapted particularly for use on impervious and worn-out soils, and on shallow open soils with an impervious foundation—in short, soils that will not absorb much water and that necessitate the removal of most of it over the surface.

By the selection and proper construction of suitable types of terraces erosion can be controlled on slopes up to 20 per cent, or even more. Instances were found where erosion was controlled by the use of terraces on land which had a slope of 30 per cent. However, slopes steeper than 20 per cent usually can be devoted more profitably to grasses or timber than to cultivated crops. Of all types of terraces, the use of the broad-base level-ridge terrace is recommended wherever conditions will permit. This type, supplemented with efficient tile drains, offers the most ideal method of preventing soil erosion on any type of soil.

The success of a terrace system depends largely upon its proper laying off. A good leveling instrument in the hands of a competent and experienced levelman is the best insurance against failure.

Construction always should begin with the highest terrace in the field, and each terrace should be completed before starting the next lower one. The late fall and early winter is the best time to build terraces.

A terrace is susceptible to failure until it has become thoroughly settled. To facilitate settling it is best not to cultivate a terrace the first year, but to sow it to a cover crop. The best results are obtained where crop rows are run parallel with the terraces.

The instructions given herein for the selection and design of terrace systems are based upon the results of surveys, observation, and a study of terraced fields in the best-terraced sections in this country and it is believed that if they are followed carefully a great increase in the efficiency of terrace systems will result and that much better opportunity will be afforded to observe the results with a view to further improving the practice of terracing. At the same time a close study of local conditions—particularly of soil—should be made which no doubt will afford more definite information for improving further the design of a terrace system adapted to a particular locality.

Since the primary purpose of terracing is to hold the soil of the farm in place and thereby both maintain its fertility and render possible an increase of fertility by proper farming methods, all of the benefits, such as greater yields and land values, which result from the preservation and increased fertility of the soil may be attributed directly to the practice of terracing. In short, the terracing of farm lands saves the soils the most substantial and valuable asset of the country.

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